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SUMMARY OF NUCLEAR AND PARTICLE ASTROPHYSICS SESSIONS [1]

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Abstract. Astrophysics is gaining increased attention from the particle and nuclear physics communities, as budget cuts, delays, and cancellations limit opportunities for breakthrough research at accelerator laboratories. Observations of cosmic rays (protons and nuclei), gamma rays and neutrinos present a variety of puzzles whose eventual solution will shed light on many issues ranging from the nature of fundamental interactions at extreme energies to the mechanisms of astrophysical sources. Several important detectors are just beginning full-scale operation and others are beginning construction.

INTRODUCTION

Astrophysics has become a growth industry in the past few years, fuelled partially by new and exciting results from projects like the Gamma Ray Observatory (GRO), partially by the diminished prospects for future accelerator-based research, and partially by the expectation that new astrophysics projects about to come on line or beginning construction (DUMAND, SuperKamiokande, SNO, MILAGRO) will provide at least partial answers to some long-standing questions.

We heard reports on a wide variety of activities, ranging from studies of cosmic rays (protons and nuclei), to the full range of the gamma ray spectrum (ie, from MeV to EeV), to neutrino detectors of all species. This brief summary is intended as a guide to the sessions; see papers in this volume by the persons named, for details, illustrations, and references.

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GAMMA RAYS

The BATSE experiment aboard GRO has provided our first really good systematic look at gamma ray bursts: transient emissions in the Mev–GeV range lasting from msec to minutes, with no simultaneous emissions below the X-ray band, and no quiescent emission from the same source at any energy. David Band reported the latest results, which indicate that while the sources are directionally isotropic within statistics, their cumulative intensity distribution deviates from the $-3/2$ power law expected for homogeneity in 3-space. This result favors the hypothesis that the bursters are distributed at cosmological rather than Galactic distance scales.

In a higher energy regime, the CYGNUS experiment at LANL has been studying potential gamma ray sources in the TeV–PeV range using relatively conventional extensive air shower (EAS) techniques, supplemented by some very cost effective water Cerenkov detectors made from commercial backyard swimming pools. As its name implies, the original motivation for CYGNUS was to investigate the muon-rich (hence presumably hadronic) EAS reportedly emanating from the direction of Cyg X3 in synch with its radio- frequency periodicity. Unfortunately, shortly after the first round of inadequately prepared experiments got on line, Cyg X3 shut down, perhaps due to budget cuts, and has not been heard from since. This is not surprising, since we don't fully understand all the long term periodicities to which our own Sun is subject, and it may be that we will hear from Cyg X3 (and Her X1 and all the other hopefuls) again. Meanwhile, the CYGNUS detector's area has been built up to 80,000 m^2 through careful incrementalism, with threshold 70 TeV and 0.5^o resolution, and the result still appears to be "no significant observations of TeV gamma ray point sources". Similar negative results are reported from searches for AGNs, all-sky surveys, periodicity scans on known lower-energy sources, and searches for Primordial Black Holes (PBHs).

Jim Matthews reported on CASA-MIA, the giant (480 meters square), beautifully instrumented air shower array centered on the Fly's Eye II site in Utah. They have proven the $< 1^o$ resolution of their detector by observing gamma-ray shadows cast by the sun and moon. Searches for 100 TeV gamma emission from point source candidates like Cyg X3, Her X1 and Crab are all negative, as are searches for signals from EGRET sources like Mk 421, and for 30 BATSE sources. With full area in operation, they expect to be able to test predictions of diffuse Galactic gamma ray intensities after a few years running.

Let me indulge in a brief editorial: the continuing saga of negative results from point source searches should be *en*couraging, not *dis*couraging, for we know that the Galaxy is swarming with cosmic rays above the TeV range, and hadronic interactions, in the sources and in the interstellar medium, have to produce pions that decay to TeV gamma rays (and neutrinos) – *unless* something funny happens to the hadronic interaction at ultra-high energies, which is becoming very hard to believe given current accelerator results, but would be great fun. So either we are merely having exceptionally bad luck regarding the correlation of source periodicities and

human scientific history, or we are about to learn something fundamental about source mechanisms or even the hadronic interaction. We should remain cheerful.

Gus Sinnis told us about plans for MILAGRO, a large-area water Cerenkov detector under construction near LANL. The existing pond at 8600' altitude has surface area $5000m^2$, and will be instrumented with 750 PMTs and 200 scintillation counters. The resulting detector will have a threshold of only 250 GeV. The project will begin data taking in 1997/8 and will provide the first TeV range all-sky survey, as well as excellent sensitivity for observations of GRBs and AGNs, and solar physics studies.

Cy Hoffman, in a separate paper, pointed out that MILAGRO will be able to observe a significant signal from evaporating PBHs, with sensitivity about 400 times that of CYGNUS.

COSMIC RAYS

Tom Gaisser outlined the theoretical issues for cosmic ray studies above 100 TeV. Our goal is to elucidate processes producing the "knee" (steepening of the spectral slope at $\sim 10^{15}$ eV) as well as the exciting prospect of exploring the "ankle" (increased slope) region at 10^{17-20} eV, where extragalactic sources come into play. To do this we need to properly extrapolate accelerator results from $\sqrt{s} \sim 1$ TeV and the central rapidity region into these enormous energies and the extreme forward direction (which is all that ground-based detectors will observe). Recent models suggest that the composition (ratio of various nuclei to protons) is energy dependent for a single supernova, but depends also upon the mix of stellar types present in the Galaxy. Extensive long-term studies of the primary spectrum and composition will be needed.

Meanwhile, as Yoshi Takahashi reported, JACEE (Japanese-American Cosmic ray Emulsion Experiment) is chipping away at the problem with incremental balloon flight exposures of emulsion chambers, building up an impressive database which is gradually approaching the knee from below. This experiment has the great advantage of using a vertex detector, so primary particles are directly observed and identified. At TeV/nucleon energies, spectra of heavy nuclei ($Z \geq 6$) are flatter than the proton spectrum, while the He/p ratio is twice that observed at 100 GeV, suggesting a heavier composition near the knee, as predicted by some models. Improvements in balloon flight capabilities make possible an explosive growth in the rate of data acquisition, given adequate support.

Gene Loh told us about observations at the other end of the graph, from Fly's Eye, the atmospheric scintillation detector in Utah which looks at the very highest energy cosmic rays due to its enormous effective area. They recently recorded an event at 3×10^{20} eV (about 50 J!). Their results on the spectrum and composition are consistent with a 2-component theory in which the Galactic flux (below 3×10^{18} eV) has a heavy (iron-rich) composition while a light (proton-rich) composition applies to the extragalactic component above that energy.

NEUTRINO EXPERIMENTS (RUNNING)

Ken Lande and collaborators are continuing to operate the Homestake chlorine detector system established by Ray Davis nearly 25 years ago. Paul Wildenhain described in detail the procedures used to ensure consistent results over this very long period of operation. There is no indication of a significant change in the multi-year average flux of solar neutrinos over the lifetime of the experiment.

Jeff Nico presented the latest update from the Russian-American Gallium Experiment, which retains the acronym SAGE despite the departure of "Soviet" from the political vocabulary. Analysis of SAGE-I (30 tons of Ga) is complete and SAGE-II (55 tons) is still running, but equipment upgrades and careful procedures to minimize effects of backgrounds still produce a result which is 0.56–0.60 of the SSM prediction.

Results from the MACRO experiment at Gran Sasso were presented by Ed Kearns. The MACRO flux limit for monopoles is approaching the Parker limit. Observations of upward-going muons allow MACRO to check the atmospheric neutrino (ν_μ/ν_e) ratio. Kamiokande and IMB reported apparent deficits relative to model predictions which might indicate neutrino oscillations. MACRO observes a deficit which does not have sufficient statistical significance to exclude the no-oscillations hypothesis.

Results from the LSND accelerator experiment at Los Alamos on possible neutrino oscillations were apparently too preliminary to go on the record, but this experiment may prove worth watching.

NEUTRINO EXPERIMENTS (UNDER CONSTRUCTION)

Ken Young described the progress made on DUMAND, which has finally become a reality after so many years of planning and detector development. In December, 1993, the basic infrastructure for the DUMAND experiment was put in place on the ocean bottom off the Big Island of Hawaii: the underwater junction box, shore cable, environmental monitoring equipment, and the first string of phototubes. Although the string controller electronics module developed a leak after 10 hours of operation, sufficient data were collected to prove successful operation of the experiment and even reconstruct some muon tracks. The problem has been fixed and three strings are to be deployed later this year or early next year, as soon as suitable ship support can be arranged.

Two major new solar neutrino experiments are in the early stages of construction, both with a 1996 turn-on date. Bhaskar Sur described progress on SNO, with emphasis on the delicate problems of background reduction and calibration. At 6800 mwe depth, and instrumented with 9500 PMTs, the SNO detector will have 1000 T of heavy water inside a vessel containing 7200 T of light water. This will provide the unique capability of observing neutral current interactions.

Todd Haines described the capabilities of Super-Kamiokande, which will come on line at about the same time as SNO. With a 22,000 T fiducial volume and over 13,000 PMTs, this huge detector should record over 8000 events per year with a 5 MeV threshold, and push proton decay lifetime limits into the 10^{34} yr range. A supernova at 10 kpc would produce over 5000 events.

PROSPECTS

The next Intersections Conference is guaranteed to see some exciting results from the many existing projects now reaching full capability as well as the new experiments just getting under way. Several speakers explicitly promised solutions of long-standing problems by the next conference, so we shall hold them to it! Thanks are due to my co-coordinator Gina Rameika, and all of the speakers mentioned above, for making these sessions a success.